RMWIA New Routing Metric for Wireless Mesh Networks

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ABSTRACT: *The Wireless Mesh Network (WMN) is a highly capable technology that can offer low-cost and easydeployable network connectivity to both small-size community networks and large-scale metropolitan networks. As a key emerging technology to provide the next generation broadband networking, WMN combines the advantages of both mobile ad hoc network (MANET) and traditional fixed network, attracting significant industrial and academic attentions.*

We present a new metric for routing in multi-radio, multihop wireless networks. We focus on wireless networks with stationary nodes, such as community wireless networks. The goal of the metric is to choose a high-throughput path between a source and a destination. Our metric assigns weights to individual links based on the Expected Transmission Time (ETT) of a packet over the link. The ETT is a function of the loss rate and the bandwidth of the link.

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1. Introduction

Wireless Mesh Networks (WMNs) are an emerging technology and are making significant progress in the field of wireless networks in recent years. Mesh networks are capable of rapid deployment and reconfiguration and this gives them advantages like low up-front cost, easy network maintenance, robustness, and reliable service coverage. Typically WMNs consist of mesh routers and mesh clients where each node can operate both as host and router. Mesh routers generally have minimal mobility in a mesh network and form the backbone of WMNs. The clients could be either stationary or mobile and can form self organized ad hoc networks which can access services by relaying requests to wireless backbone network. But, because the aim of WMN is to diversify the capabilities of the ad hoc network, more sophisticated algorithms and design principles are required for the realization of WMNs. Some of the differences between WMNs and ad hoc networks are : (1) The mesh routers in WMN form the backbone which provides large coverage, connectivity and robustness. But in ad hoc networks, the connectivity depends on the individual contribution of end-users. (2) The gateway and bridging functionalities in mesh routers provide the integration of WMN's with other networks such as Internet, cellular, IEEE 802.11, IEEE 802.15, IEEE 802.16 and sensor networks. Unlike ad hoc networks, the routing and configuration functionalities of the mesh routers reduces the load on enduser devices. (3) The mesh routers can be equipped with multiple radios to perform routing and access functionalities which improves the capacity of the network. On the other hand, ad hoc networks use same channel for routing, network access, etc., which result in poor performance. (4) Unlike in WMNs, we run into several challenges with routing protocols,network configuration and deployment in ad hoc networks because its topology depends on the movement of users. The mesh network is dynamically self-organizing and self configuring, with the nodes in the network automatically establishing and maintaining connectivity among themselves. These features provide many advantages for WMN's like good reliability, market coverage, scalability and low upfront cost. WMN gained significant attention because of the numerous applications it supports, e.g., broadband home networking, community and neighbourhood networks, delivering video, building automation, in entertainment and sporting venues, etc. Currently, hotspot IEEE 802.11 WLAN deployments are prevalent across coffee shops. A couple ofobvious problems with this deployment is the location of access points and the presence of dead zones without service coverage. Though site surveys can be done to eliminate dead zones, it is very expensive installation of multiple access points can also be prohibitive cost-wise. The issue with access points can be resolved by replacing access points with mesh routers. In WMN, the mesh routers cooperatively route each other's packet to destination. This results in flexible communication.

The issue with dead zones can be eliminated inexpensively by adding more mesh routers or by changing the power level or location of mesh routers. The other wireless networks are not capable of multi-hop networking and hence mesh network is most suited for coffee shops, airports, hotels, etc.

In our paper, we focus on design of good routing metric for routing protocols in WMNs. In WMNs, a routing protocol provides one or more network paths over which packets can be routed to the destination We have surveyed multiplerouting metrics that have been proposed for routing protocols in WMNs. Rest of our document is organized as: (1). We define the characteristics of a good routing metric. (2). An overview of routing protocols used in WMNs (3). Survey report on each of the routing metric we have studied in our work (4). We present a new routing metric we have proposed in this paper (5). Finally, we cover conclusion and scope for future work

2. Routing Protocols Uisng for Wireless Mesh Networks

2.1 Destination Source-Routing Protocol (DSR)
2.2 Destination Sequence Distance Vector Routing Protocol (DSDV)
2.3 Ad-hoc On-demand Distance Vector Routing Protocol (AODV)

3. Characteristics of Routing Metrices

3.1 Interference
Interference in a mesh network can be of three types:

• **Intra-Flow Interference:** Intra-flow interference occurs when the radios of two or more links of a single path or flow operate on the same channel and can be reduced by increasing channel diversity.

• **Inter-Flow Interference:** Inter-flow interference is the interference caused by other flows that are operating on the same channels and are competing for the medium

• **External interference:** External interference occurs when a link experiences interference outside of the control of any node in the network.

3.2 Locality of Information
Some metrics require information such as channels used on previous hops of a path, or other metrics observed on other nodes of the networks, such as packet delivery rate or noise levels. This non-local information can be part of routing metric and can be used to make more optimal routing decisions.

3.3 Load Balancing
The ability of a metric to balance load and provide fairer usage of the networks distributed resources.

3.4 Agility
The agility of a metric refers to its ability to respond quickly and efficiently to changes in the network in terms of topology or load. In order for a metric to be considered agile, the rate at which measurements are taken should be higher than the rate of change in the network.

3.5 Isotonicity

The isotonic property of a routing metric means that a metric should ensure that the order of weights of two paths is preserved if they are appended or prefixed by a common third path.

3.6 Throughput

In general, a metric should be able to select routes with greater throughput consistently.

4. Performance Metric

In terms of four aspects: error rate, bandwidth, latency, and jitter. In this section, we use four performance metrics which are average packet delivery ratio, average throughput, average end-to-end delay and average jitter in the simulation. We show the explanation of these performance metrics as follows.

4.1 Error rate

The packet delivery ratio measures the percentage of packet delivery rate which is widely considered to measure error rate as a key point of the communication quality aw-re networks.

4.2 Bandwidth

It is the transmission rate of traffic flow in the network. It is referred to the throughput in WMNs, where the throughput calculates the capability of the network to accommodate traffic/messages. A higher throughput of the multicast session determines greater bandwidth provided for the communication. The average throughput calculates the average capability of the network to accommodate traffic/messages.

4.3 Latency

The end-to-end delay is the time consumed to carry a packet from a source to a destination. The average end toend delay is the average time in which a packet travels from a source to a destination.

4.4 Jitter

Is the latency variation in the network. The average jitter measures the variance of the packets arrival times at the destinations.

5. Routing Metric

In this section, we describe a series of existing routing metrics, and then show how they work, focusing on their abilities to satisfy the requirements of WMN

5.1 Hop Count

Hop count is the traditional routing metric used in most of the common routing protocols (AODV, DSR, DSDV) designed for multi-hop wireless networks.

This metric treats all links in the network to be alike and finds paths with the shortest number of hops. It also does not account for data rate and interference experienced by the links. This can often result in paths which have high loss ratio and therefore, poor performance.

5.1.1 Advantages

a). Hop-count is a metric with high stability and further has the isotonicity property, which allows minimum weight paths to be found efficiently.

5.1.2 Drawbacks

It may choose paths with low throughput and Poor medium utilization, as slower links take more time to send packets.

5.2 Expected Transmission Count (ETX) [3, 1, 10]

Is a metric to estimate the expected number of MAC layer transmissions for the wireless links and measure the packet loss rate which is proposed by De Couto et al. A node sends out probe packets to all its neighbor nodes every second. When a neighbour node receives probes, it increments the amount of received packets and calculates the loss rate of packet every 10 s. The weight of a route is the sum of the *ETX* of all links along the path. The possibility of successful packet transmission from source a to destination b in a wireless link is:

$$p = (1 - pf) \times (1 - pr) \quad (1)$$

Then *ETX* can be achieving as:

$$ETX = \sum_{k=1}^{\infty} (1 - P)^{k-1} KP\ k = 1 / 1 - P \quad (2)$$

Where pf is the probability of successful forwarded packets and pr denotes the probability of successful received packets. The advantages of *ETX* are the reduced probing overhead and non self-interference as the delay is not measured. However, *ETX* cannot measure the cause of data size in the delivery ratio and it do not consider the transmission rate. Furthermore, unicast probing of *ETX* is not accurate as differences between broadcast and unicast.

5.2.1 Advantages

a). *ETX* is based on delivery ratios, which directly affects throughput and accounts for the effects of link loss ratios and asymmetry in the loss ratio in both directions of each link.

b). It favors paths with higher throughput and lower number of hops as longer paths have lower throughput due to intra-flow interference.

c). *ETX* deals with inter-flow interference indirectly. As *ETX* measures link-layer losses, the links with a high level of interference will have a higher packet loss rate and therefore higher *ETX* value.

d). *ETX* is isotonic and therefore allows efficient calculation of minimum weight and loop-free paths.

5.2.2 Drawbacks

a). It is a routing metric for single-channel multihop wireless network.

b). It only captures link loss ratio ignoring the interference experienced by the links which has a significant impact on the link quality and the data rate at which packets are transmitted over each link.

c). It does not consider differences in transmission rates.

d). As the transmission rate of probe packets is typically low, it does not accurately reflect loss rate of actual traffic.

e). It does not give any information on the effective link share.

f). As it does not consider load of the link, it will route through heavily loaded nodes leading to unbalanced resource usage.

g). *ETX* does not discriminate between same channel paths and channel-diverse paths. So, it makes no attempt to minimize intra flow interference.

h). In highly mobile single radio environments, *ETX* shows poor agility due to long time window over which it is obtained.

5.3 Expected Transmission Time (ETT) [4, 5]

Measures the MAC layer transmission time of a packet over a link l. It considers the impact of link transmission rate and packet size so as to improve the performance of *ETX*. The relation between *ETT* and *ETX* is formulated as follows:

$$ETTl = ETXl \times (s / bl) \quad (3)$$

where *s* : is the packet size

bl is the bandwidth of link l.

The ETT value of a path also can be seen as the transmission latency. However, *ETT* still suffers from the inaccurate measurement of the unicast probing.

5.3.1 Advantages

a). It can increase the throughput of path by measuring the link capacities and would increase the overall performance of the network

b). *ETT* is isotonic.

5.3.2 Drawbacks

a). *ETT* retains many disadvantages of *ETX*.

b). *ETT* does not consider link load explicitly due to which it cannot avoid routing traffic through already heavily loaded nodes and links.

c). *ETT* is not designed for multiradio networks so it does not minimize intra-flow interference.

5.4 Weighted Cumulative ETT (WCETT) [4]:

Is also proposed by Draves et al. and it considers the multiradio nature of the WMNs in two components: the total transmission time along all hops in the WMN and the channel diversity in the path.

The *WCETT* of a path *p* is:

$$WCETT\,(r) = (1-p)\,ETTl + p\,max_{1 \le j \le k}\,Xj \qquad (4)$$

Where Xj is the number of times that channel j used by path r. p is a parameter as $0 \le p \le 1$. Therefore, $pmax_{1 \le j \le k}\,Xj$ denotes the maximum number of times that the same channel j is used along a path. Although it captures the intra-flow interference of a path with measuring the channel assignment time, it does not consider the inter-flow interference. Thus, traffic flows may be routed to the dense area by *WCETT*. One more important problem of the *WCETT* is that it is not isotonic which generates a forwarding loop while chosen a path.

5.4.1 Advantages

a).*WCETT* effectively considers intra-flow interference into account and selects channel diversified paths.

b).It retains all the advantages of *ETT* except isotonicity.

c).It manages to improve the performance of multi-radio, multi-rate wireless networks when compared to simpler metrics such as *ETT*, *ETX* and hop count.

d).The two weighted components tuned by α of *WCETT* substitutes the simple summation of *ETT* and attempt to strike a balance between throughput and delay.

5.4.2 Drawbacks

a). WCETT simply considers the number of links operating on the same channel and their respective *ETT*s but does not consider the relative location of these links. It assumes all links of a path operating on same channel interfere which can lead to selection of non-optimal paths.

b). Because of the second term, *WCETT* is not isotonic. If a metric is not isotonic, then it is very difficult to use with link state routing protocols.

c). *WCETT* does not explicitly consider the effect of inter flow interference. Due to this, it may establish routes which suffer from high levels of interference.

d). This metric suffers from same limitations as *ETX/ETT* by not estimating the effective link share.

5.5 LAETT

The two main goals of *LAETT* [1] is to provide a path which satisfies the bandwidth request of the flow and to leave room for future requests by balancing the load across the network. It combines wireless access characteristics and load estimates. It consists of an adaption of *ETT* metric

$$ETTij = ETTij \times (S/Bij) \qquad (5)$$

$ETXij$ = Expected transmission count on link (i, j)

S = Packet size

Bij = Effective bit rate

$Bij = (Bi\,/\,\mu ij)$

Bi = Transmission rate of node i

μij = Link quality factor

μij = 1 when the link of good quality when the transmission quality degrade, μij increases and Bij decreases

To consider load balancing, remaining capacity (*RCi*) on each node is introduced and it is given by

$$RCi = Bi - \sum_{k=1}^{N} \mu ik * fik \tag{6}$$

f ik are the transmission rates of the *Ni* current flows that traverse node *i*. The cost of a flow on remaining capacity is weighted by factor μik: good quality transmissions use less resources than bad quality ones. The packet pair algorithm can be used to estimate the available bandwidth on a link which provides μij .We define *LAETTij* by:

$$LAETTij = ETXij * S * 2\ \mu ij * (RCi + RCj) - 1 \tag{7}$$

The second factor captures the remaining capacity at bothend nodes. When two paths have same cumulative weight in terms of *ETX*, *LAETT* metric favors the one with the most remaining capacity.

5.5.1 Advantages

a). LAETT is a load aware isotonic routing scheme that uses weighted shortest path routing to balance the load across the network.

b). It captures link quality and traffic load.

5.5.2 Drawbacks

a). It does not consider intra flow interference and does not explicitly consider inter flow interference.

5.6 EETT: Exclusive Expected Transmission Time (EETT) [6]

Is a novel interference aware routing metric which selects multi-channel routes with least interference to maximize end to end throughput. It is used to give better evaluation of a multichannel path. For any given l, Interference set (IS) is defined as the set of links that interfere with it. A links interference set also includes the link itself.

The link l's *EETT* is defines as :

$$EETTl = \sum_{linki \in IS(l)} ETTi \tag{8}$$

IS (*l*) = Interference set of link l. The path weight is defined as the sum of *EETT*'s of all links on the path.

5.6.1 Advantages

a).As this metric builds over *ETT*, it has all the advantages of *ETT*.
b). It effectively considers intra flow interference and indirectly considers inter-flow interference,and *EETT* is isotonic.
c). *EETT* is isotonic.

5.6.2 Drawbacks

a). *EETT* of link l represents the busy degree of the channel used by link l. It is the worst case estimation of transmission time for passing link l.

5.7 Metric of Interference and Channel Switching (MICS)

In [7], the authors propose *MIC* which improves upon *WCETT* by considering inter-flow interference. *MIC* for a path is defined as follows:

$$MIC(P) = 1/N * \min(ETT) \sum_{linkl \in p} IRUl + \sum_{nodei \in p} CSCi \tag{9}$$

where *N* is the total number of nodes in the network. The two components IRU and CSC are defined as follows:

$$IRUl = ETTl * Nl$$

$$CSCi = \begin{cases} \omega 1 = \text{if } CH(prev(i)) \neq CH(i) \\ \omega 2 = \text{if } CH(prev(i)) = CH(i) \end{cases} \tag{10}$$

$$0 \leq \omega 1 \leq \omega 2$$

where *Nl* is the set of neighbors that interfere with the transmissions on link l. *CH* (*i*) represents the channel assigned for node *i*'s transmission and *prev* (*i*) represents the previous hop of node i along the path *p*. *MIC* is also non-isotonic because of the second component (CSC) and the authors in [7], demonstrate somewhat complex ways to form virtual nodes and make the metric isotonic.

Note that *MIC* incorporates inter-flow interference by scaling up the *ETT* of a link by the number of neighbors interfering with the transmission on that link. In practice, the degree of interference caused by each interfering node on a link is not the same.

It depends on the signal strength of the interferer's packet at the sender or the receiver. This varies depending on the position of the interferer with respect to the actual sender or receiver and the path loss characteristics. Also, the degree of interference depends on the amount of traffic generated by the interfering node. Even when the interferer is close to the sender or the receiver and is not involved in any transmission simultaneously, it does not cause any interference. *MIC* fails to capture the above mentioned characteristics of interference.

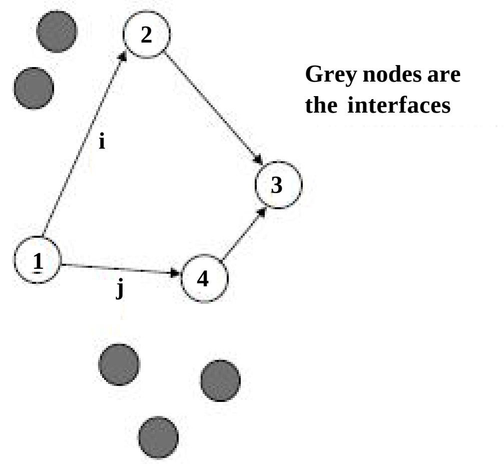

Figure 1. Understanding interference

For example, consider Figure 1. Let us assume that each node generates uniform traffic. Consider the two links *i* and *j* with *ETTi* > *ETTj* Link i has two interfering neighbours which are close to the nodes 2 and cause high degree of interference. *Link j* has three interfering neighbours which cause less interference.

MIC favours link i over link *j* resulting in choosing the link with higher *ETT* and poor throughput.

The second component (CSC) captures intra-flow interference only in two consecutive links. The authors in [7] generalize it, but the decomposition of the nodes into virtual nodes to make the metric isotonic becomes more complicated.

MIC favours links incident on nodes with less number of interfering neighbours irrespective of whether the neighbour causes any interference or not. This results if finding paths along the boundary of the network where nodes have less number of neighbours and find longer paths. We observe this from our experimental results.

6. Proposed Routing Metric

Routing Metric With Interference Aware (*RMWIA*) is my proposed metric. Our routing metric captures the effects of variation in link loss-ratio, differences in transmission rate as well as inter-flow and intra-flow interference.

$$RMWIA = (1-\beta) * \sum_{i=1}^{n} \left(\frac{ETXj}{IRj} \right) + \beta^{*} max \leq 1j \leq k\, Xj \qquad (11)$$

Our routing metric captures the effects of variation in link loss-ratio, differences in transmission rate as well as inter-flow and intra-flow interference.

When there is no interference in the network, ETX captures the quality of the link quite well as links with less expected transmission time give better throughput. But when there are more interfering flows in the network, this is not the case. We need to factor in the varying interference experienced by a link into the routing metric to find good quality paths. In order to do this, we need to model interference properly and factor it in the metric.

Xj is same as in *WCETT*. The *Xj* value of a link *j* is defined as follows:

$$Xj = \frac{ETXj}{IRj} = ETXj \,/\, IRj \qquad (12)$$

IRj =Interference ratio for a link *j* is the value between two nodes *u* and *v*. It is defined as follows:

$$IRj = min\,(IRj\,(u);\, IRj\,(V))$$

Interference ratio (IR) value for a link *j* is the value between two nodes *u* and *v*. It is defined as follows.

$$IRi\,(u) = SINRi\,(u) \,/\, SNRi\,(U)$$

6.1 Explanations

a).In *RMWIA* metric, we first calculate the *ETX* values of all the links in the path.

b).This *ETX* value considers the link quality, remaining capacity and packet size into consideration.

c).For any link in the path, the *ETX* value of the link is summation of all the *ETX* values of links which are in the interference set (IS) of this link.

d).If there are more neighboring links on the sane channel with link l, link l may have to wait for a longer period to do the transmission on that channel. As a result, a path with larger *ETX* indicates that it has more severe interference and needs more time to finish the transmission over all links within the path. In essence, a better channel distribution over a path results in less intra-flow interference.

e).Hence *ETX* can accurately reject the optimality of channel distribution on a path. The interference Ratio (*IRj*) calculates the inter-flow and external interference.

6.2 Advantages

a). It even considers load balancing as it uses *ETX* metric which takes care of load balancing.

b). RMWIA does not have an individual summation component that captures intra flow interference. As explained above, *ETX* considers intra flow interference in *RMWIA* and hence is isotonic.

c). It has all advantages *ETX*, *EETT* and *LAETT* routing metrics. Below is a table that summarizes characteristics of all the routing metrics we have studied so far including *RMWIA*.

	Hop	ETX	ETT	WCETT	LAETT	EETT	MICS	RMWIA
Intra	Non	Non	Non	Yes	Non	Yes	Yes	Yes
Inter	Non	Yes*	Yes*	Yes*	Non	Yes*	Yes#	Yes
External	Non	Non	Non	Non	Non	Yes	Yes	Yes
Load bal	Non	Non	Non	Non	Yes	Non	Non	Yes
Agility	Yes	Non	Non	Non	Non	Non	Non	Non
Isotonic	Yes	Yes	Yes	Non	Yes	Yes	Yes§	Yes
Stable	Yes	Non	Non	Non	Non	Non	Non	Non

* INDIRECTLY # NOT ACCURATE § COMPLEX

7. Conclusion and Future Work

This article has sought to provide a thorough analysis of the state-of-the-art with regard to the cross-layer routing metrics for *WMN*. The evolution of routing metrics has led to an increase in the complexity of route computation with the adoption of new measurements. For example, with the emergence of cross-layer routing metrics that combine interference-aware and load-aware routing elements. As a result of advances in the research on routing metrics, there is a need for a systematic and detailed approach to their classification and accompanying analysis. To fill this gap, an attempt has been made to conceive a new taxonomy for the classification of cross-layer routing metrics which relies on three key characteristics - measurements, information gathering methods and stability mechanisms. It is worthwhile to point out that the previous surveys on routing metrics describe few about measurements and do not take into consideration the information gathering methods and stability mechanisms. Thus, the most relevant routing metrics for *WMN* have been described in accordance with the mainelements of the proposed taxonomy.

We presented a new Routing Metric with Interference Aware (*RMWIA*) that aids in finding paths that are better in terms of reduced inter-flow and intra-flow interference.

We incorporated this metric and new support for multi-radio networks in the well known *AODV* routing protocol to design an enhanced AODV-MR routing protocol.

As future work, we propose to implement *RMWIA*, metric using network simulators such as ns2 software and evaluate their performance in comparison with some of the routing metrics we have considered in this survey.

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